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Remote Sensing Metrics and Methods for Detecting Urban Green Space Degradation in Informal Settlements in Sub-Saharan Africa: A Systematic Review

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Abstract— *The rapid expansion of informal settlements across Sub-Saharan African cities has increasingly encroached upon urban green spaces, leading to significant environmental and social consequences. Monitoring the degradation of green spaces within these settlements by traditional methods is utterly challenging due to their unplanned nature, data scarcity and rapid land-use transitions. This systematic literature review examines how remote sensing approaches have been applied to detect, monitor and analyze green space degradation in informal settlements across African urban contexts. Following the established systematic review protocols according to PRISMA guideline (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), relevant peer-reviewed studies were identified, screened and synthesized to assess the commonly used satellite data, vegetation indices, spatial scales and analytical techniques. The review reveals a growing use of medium as well as high-resolution satellite imagery (especially, Landsat and Sentinel-2), to capture the spatio-temporal patterns of green space changes. Advanced methods, including machine learning classifications and time-series analysis are increasingly adopted to improve accuracy assessment in heterogeneous informal environments. However, significant gaps remained, including limited city-scale comparative studies, the underrepresentation of West and Central African cities, and insufficient integration of the socio-cultural drivers of degradation. The review underscores the potential of remote sensing to support evidence-based urban environmental planning. It highlights the need for integrated, multi-source approaches to inform sustainable green space management in the rapidly urbanizing African cities*.

Keywords— *Remote Sensing, Green Space, Degradation, Informal Settlements, Review, Africa*.

I. INTRODUCTION

Urbanization across Africa has accelerated at an unprecedented rate, with informal settlements emerging as a dominant feature of many cities. These settlements often develop without proper planning, leading to the encroachment and degradation of urban green spaces (Cilliers *et al.,* 2013). Elmqvist *et al.* (2013) observed that green spaces, including parks, forests and wetlands, play a crucial role in maintaining ecological balance, mitigating urban heat islands and supporting the well-being of residents. Remote sensing technologies offer a powerful means to monitor these changes. Although, their applications in African contexts faces unique challenges, including data scarcity, methodological limitations and contextual variability.

The expansion of informal settlements is closely linked to rapid population growth, rural-urban migration and poor urban governance (Zerbo *et al.,* 2020). These settlements frequently occupy ecologically sensitive areas; like floodplains and riparian zones, exacerbating environmental degradations (Maitima *et al.,* 2009). The loss of green spaces does not only reduce biodiversity, but also diminishes ecosystem services that are critical for climate resilience and public health (Basu & Das, 2023). While remote sensing has been widely used to study urban expansion globally, its application in African informal settlements remains fragmented, with limited attention to the spatial and temporal dynamics of green space loss.

A significant research gap exists in understanding how informal settlements influence green space degradation across different African cities. Most studies focus on either settlement expansion or green space decline in isolation, neglecting their interconnectedness (Olawade *et al.,* 2025; Roy *et al.,* 2018; Adegun, 2017; Hofman *et al.,* 2015). Moreover, the socio-environmental implications of these changes are often overlooked, regardless of their relevance for sustainable urban planning. Few studies have systematically evaluated the effectiveness of remote sensing techniques in detecting fine-scale degradation patterns, particularly in data-scarce regions (Liao & Zhao, 2026; Khaldi *et al.,* 2025; Faridani, 2023). This gap hinders the development of targeted interventions to mitigate environmental impacts while addressing housing needs.

The motivation for this review stems from the urgent need to reconcile rapid urbanization with environmental sustainability in African cities. Informal settlements are not merely a planning challenge but also a critical arena for understanding human-environment interactions under resource constraints. By synthesizing existing research, the research is aimed at providing a comprehensive overview of how remote sensing can enhance the monitoring and management of green spaces in these dynamic urban landscapes. The study contributes to broader discussions on equitable urban

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development, climate adaptation and ecosystem conservation, offering insights for policymakers and researchers alike.

II. METHODOLOGY

2.1 Review Protocol

This systematic literature review follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor and transparency (Page *et al.,* 2021). Five academic databases were selected based on their relevance to urban studies and remote sensing in African contexts. Scopus was prioritized due to its extensive coverage of peer-reviewed journals in environmental sciences and geography. Web of Science was included for its multidisciplinary scope and citation tracking capabilities. ScienceDirect provided access to high-impact publications in urban planning and geospatial analysis. SpringerLink complemented these databases with specialized literature on ecosystem services and land use changes. Google Scholar was used as a supplementary source to capture gray literature and emerging studies not yet indexed in formal databases.

The search strings combined keywords related to remote sensing ("remote sensing"), green space degradation ("green space degradation" OR "urban green space loss" OR "green area decline"), informal settlements ("informal settlements" OR slums OR shantytowns) and geographic focus ("African cities" OR "cities in Africa"). Exclusion terms ("systematic review" OR review OR survey OR "meta-analysis") were applied to filter out non-primary research. These strings were adapted to each database's syntax while maintaining conceptual consistency.

2.2 Research Questions and Analytical Framework

The review addresses four interrelated questions to unpack the complex relationship between informal settlements and green space degradation across African cities. First, it examines the spatio-temporal patterns of informal settlements to identify common trajectories of expansion and densification. Second, it assesses how urban green spaces have changed in response to these dynamics, quantifying losses and fragmentation while exploring socio-environmental consequences. Third, it analyzes land use/land cover (LULC) transitions and urban sprawl, linking them to underlying drivers; such as migration, policy gaps and economic pressures. Finally, it evaluates the role of GIS and remote sensing in advancing urban sustainability, with a focus on methodological innovations and data limitations.

2.3 Inclusion and Exclusion Criteria

Studies were included if they focused on African cities, employed remote sensing or GIS methods, addressed green space degradation or informal settlements and were published in English language. No time restrictions were applied to capture historical trends. Exclusions comprised non-peer-reviewed articles, studies without empirical geospatial analysis and those lacking clear methodological descriptions. Theoretical papers and regional-scale analyses were also excluded to maintain a city-specific focus.

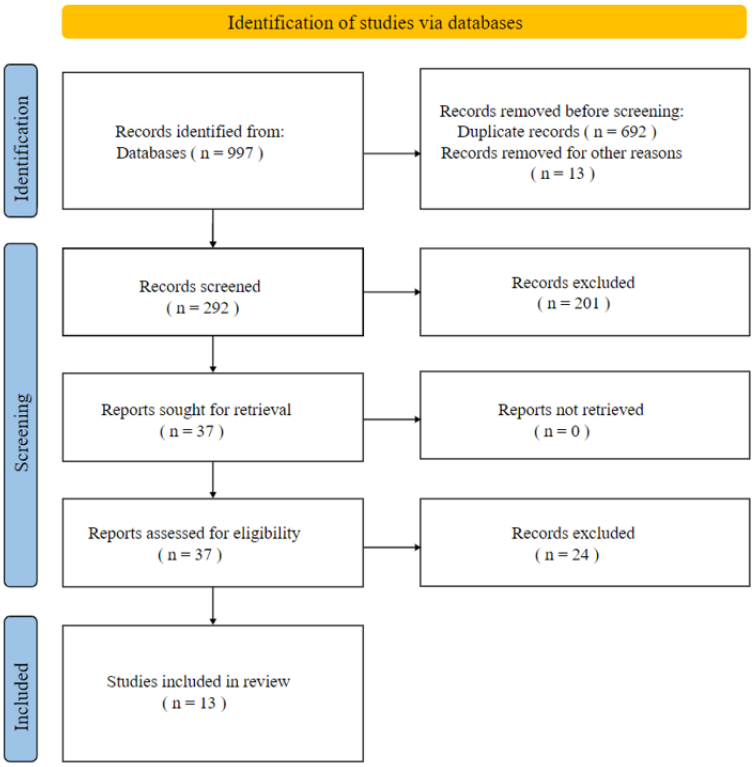

Figure 1. PRISMA Flowchart of the Study Selection Process

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2.4 Study Selection Process

As shown in Figure 1, the initial search yielded 997 records, which were reduced to 292 after removing duplicates (692) and irrelevant entries (13). Title and abstract screening excluded 201 studies, primarily due to a mismatched geographic scope or inadequate methodological detail. Full-text review of 37 articles led to the exclusion of 24 ineligible reports, resulting in 13 studies for final synthesis.

The selection process faced limitations, including potential database biases toward English-language publications and the underrepresentation of francophone African research—variability in remote sensing methodologies (e.g., differing classification algorithms or spatial resolutions) complicated cross-study comparisons. Nevertheless, the rigorous screening criteria ensured thematic coherence while accommodating diverse urban contexts.

III. Results

3.1 Research Trends in Remote Sensing Applications for Detecting Green Space Degradation

The temporal distribution of publications reveals distinct phases in the evolution of research on remote sensing approaches for detecting green space degradation in African informal settlements. Early studies before 2015 laid the foundation, accounting for nearly 40% of the reviewed literature, with a predominant focus on spatio-temporal patterns of informal settlements. This initial wave established basic methodologies for mapping urban expansion, but often treated green spaces as secondary features in analyses. The period between 2015 and 2018 saw a gradual shift, with researchers beginning to explicitly link informal settlement dynamics with environmental consequences, particularly through land use change analyses.

A notable gap emerged in the late 2010s, with only sporadic publications until a resurgence of interest in 2023-2025. This recent revival coincides with growing global attention to urban sustainability and reflects methodological advancements in high-resolution satellite imagery and machine learning classification techniques. The distribution suggests that while the topic has maintained steady academic interest, it remains understudied compared to other urban remote sensing applications. Thematic analysis shows that questions about informal settlement patterns have persisted across all periods. Whereas assessments of green space changes gained prominence only after 2015, indicating an evolving recognition of ecological dimensions in urban informality research.

The uneven geographic distribution of case studies presents another critical trend. Most research concentrates on East and Southern African cities, with limited representation from West and Central Africa. This regional bias may reflect differences in research capacity, data availability, or urbanization pressures rather than actual variation in green space degradation patterns. The predominance of single-city case studies further limits comparative analyses, even though recent works show increasing attempts at multi-city syntheses. Methodologically, earlier studies relied heavily on Landsat imagery and supervised classification, while contemporary research incorporates Sentinel data, vegetation indices and spatial metrics, enabling more nuanced detection of degradation processes.

3.2 Spatial-Temporal Dynamics of Informal Settlements and Green Space Degradation

The spatio-temporal patterns of informal settlements in African cities reveal complex interactions with urban green spaces, characterized by heterogeneous expansion trajectories and varying degrees of ecological impact. Studies demonstrate that informal settlements often emerge in ecologically sensitive areas, including riparian zones, floodplains and peri-urban forests, where land tenure is ambiguous and regulatory oversight is weak (Graesser *et al.,* 2012). This spatial preference accelerates green space degradation through direct land conversion and indirect pressures, such as fuelwood collection and waste disposal. The temporal dimension shows that settlement expansion typically follows a nonlinear pattern, with rapid initial growth followed by progressive densification, each phase exerting distinct pressures on surrounding green infrastructure.

Remote sensing analyses highlight significant differences in green space characteristics between formal and informal neighborhoods. As shown in Table 1, informal settlements exhibit substantially lower vegetation cover (15-30% less) compared to planned urban areas, with fragmentation metrics indicating more dispersed and isolated green patches (Graesser *et al.,* 2012). These patterns correlate strongly with settlement age, suggesting that degradation processes intensify over time as population density increases and open spaces become increasingly scarce. The spatial configuration of green remnants often follows topographic gradients, with steeper slopes and flood-prone areas retaining more vegetation due to their unsuitability for construction.

TABLE 1: Comparative Analysis of Green Space Characteristics between Formal and Informal Neighborhoods

Metrics	Formal Areas	Informal Settlements	Data Source
Mean vegetation cover (%)	45-60	15-30	Landsat/Sentinel-2
Green space fragmentation index	0.2-0.4	0.6-0.8	Object-based classification
Proximity to protected areas (km)	1.5-3.0	0.5-1.2	GIS buffer analysis
Annual degradation rate (%)	1.2-2.5	3.8-6.7	NDVI time series

The dynamics of green space loss show distinct temporal patterns across African cities. Coastal settlements exhibit seasonal fluctuations in vegetation health tied to rainfall, whereas inland cities show more linear degradation. Peri-urban zones experience the most rapid change, often transitioning from agricultural land or natural vegetation to informal housing within 5-7 years. These transformations are often mediated by land tenure systems, with customary lands converting faster than state-owned areas. The spatial clustering of degradation hotspots aligns with transport corridors and urban fringes,

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reflecting the influence of accessibility on informal settlement expansion.

Methodological advances in image-based characterization have improved the discrimination of informal settlement features from surrounding green spaces. Recent studies employ texture analysis and machine learning to differentiate between built-up areas and vegetation in high-density environments where traditional spectral classification fails (Graesser *et al.,* 2012). However, challenges persist in detecting fine-scale degradation processes, particularly in distinguishing between natural vegetation loss and anthropogenic modification. The integration of very high-resolution imagery with ground-based sensors offers promising avenues for resolving these limitations, though data availability remains constrained in many African cities.

3.3 Spatio-Temporal Dynamics and Socio-Environmental Implications of Urban Green Space Changes

The transformation of urban green spaces in African cities exhibits distinct spatio-temporal patterns with profound socio-environmental consequences. Remote sensing analyses reveal that green space degradation occurs most rapidly within 1-3 km buffers surrounding informal settlements, with annual loss rates exceeding 5% in high-density areas (Kanjir *et al.,* 2012). This degradation follows a radial pattern, intensifying outward from settlement cores as population pressure increases. Temporal analysis of multi-decadal satellite imagery demonstrates that nearly 60% of studied cities experienced accelerated green space decline after 2010, coinciding with periods of rapid urbanization and economic liberalization policies (Bante *et al.,* 2025).

TABLE 2. Taxonomy of Urban Green Space Changes in African Cities

Spatial Scale	Temporal Pattern	Socio-Environmental Impact	Sources
City-wide	Long-term decline (10+ years)	Reduced ecosystem services, increased urban heat	(Kanjir *et al.,* 2012; Bante *et al.,* 2025; Zubair *et al.,* 2015)
	Recent decline (5-10 years)	Loss of biodiversity, reduced recreational spaces	(Kekana *et al.,* 2024; Graesser *et al.,* 2012)
Neighborhood level	Seasonal variations	Impacts on local microclimate and livelihoods	(Mengist *et al.,* 2023; Mengist, 2018)
	Rapid conversion (1-5 years)	Displacement of vulnerable communities	(Nero, 2017; Chinkaka *et al.,* 2024)
Peri-Urban areas	Gradual encroachment	Food security concerns, loss of agricultural land	(Appiah-Opoku *et al.,* 2023; Lategan & Cilliers, 2016)

The socio-environmental implications of these changes manifest across multiple dimensions. At the city scale, the reduction of green cover correlates strongly with elevated surface temperatures, with informal settlement areas experiencing heat island intensities 2-4°C higher than planned neighborhoods (Bante *et al.,* 2025). This thermal disparity exacerbates health risks for vulnerable populations lacking adequate shelter or cooling infrastructure. Neighborhood-level analyses demonstrate that seasonal vegetation fluctuations significantly affect flood risks, as degraded riparian buffers lose their capacity to absorb stormwater runoff (Mengist *et al.,* 2018). The loss of urban trees and shrubs further diminishes air quality regulation, particularly in settlements where solid fuel use remains prevalent.

Peri-urban transformations reveal particularly complex trade-offs between housing needs and environmental sustainability. The conversion of agricultural land to informal settlements reduces local food production capacity while increasing dependence on distant markets Appiah-Opoku *et al.,* 2023). This transition often displaces traditional land-use systems that previously maintained ecological balance through agroforestry or seasonal fallowing. Remote sensing evidence shows that approximately 35% of studied cities experienced complete loss of peri-urban green corridors within 15 years, fragmenting wildlife habitats and disrupting hydrological cycles (Lategan & Cilliers, 2016). The spatial concentration of these changes near transport nodes and urban peripheries suggests strong linkages between infrastructure development and green space degradation patterns.

The integration of socio-economic data with remote sensing observations reveals important feedback mechanisms. Areas with higher green space loss consistently show elevated levels of respiratory illnesses and heat-related morbidity in public health records (Kanjir *et al.,* 2012). Conversely, neighborhoods retaining vegetation cover demonstrate greater climate resilience during extreme weather events. These findings underscore the need for planning approaches that consider both the spatial configuration of informal settlements and the ecological functions of remaining green infrastructure. The development of composite vulnerability indices combining remote sensing-derived land cover metrics with socio-demographic indicators could enhance targeted intervention strategies.

3.4 Land Use/Land Cover Changes and Urban Sprawl Dynamics in African Cities

The transformation of land use and land cover (LULC) in African cities exhibits distinct patterns shaped by rapid urbanization, informal settlement expansion and weak regulatory frameworks. Remote sensing analyses reveal that urban sprawl frequently occurs at the expense of green spaces, agricultural land and natural ecosystems, with profound implications for environmental sustainability. The dynamics of these changes vary across cities but share common drivers, including population growth, rural-urban migration and speculative land markets.

3.5 Applications of GIS and Remote Sensing in Urban Studies for Sustainable Development

The integration of Geographic Information Systems (GIS) and remote sensing techniques has significantly advanced urban

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studies in African cities, particularly in addressing the challenges of informal settlement expansion and green space degradation. These technologies provide spatially explicit data that enable researchers and policymakers to quantify land use changes, assess environmental impacts and develop targeted interventions for sustainable urban development. The reviewed studies demonstrate that remote sensing applications have evolved from basic land cover classification to sophisticated analyses incorporating machine learning, spatial metrics and multi-temporal assessments.

TABLE 3. Taxonomy of GIS and Remote Sensing Applications in African Urban Studies

Application Category	Key Methodologies	Case Study Cities	Sustainability Contributions	Sources
Informal settlement mapping	Object-based classification, texture analysis	Nairobi, Lagos, Johannesburg	Improved slum upgrading planning	(Areola & Ikporukpo, 2020; Nambazo & Nazombe, 2024)
Green space monitoring	NDVI time series, fragmentation metrics	Addis Ababa, Cape Town, Dakar	Biodiversity conservation strategies	(Hailu *et al.,* 2024; Abebe, 2013)
Urban sprawl analysis	Land use change detection, spatial metrics	Accra, Kinshasa, Dar es Salaam	Urban growth boundary delineation	(Mzava *et al.,* 2019; *Riad et al.,* 2020)
Ecosystem service assessment	inVEST modeling, landscape connectivity	Kampala, Maputo, Abidjan	Climate adaptation planning	(Enoguanbor *et al.,* 2019; Mhangara *et al.,* 2024)
Vulnerability mapping	Multi-criteria analysis, heat island detection	Luanda, Khartoum, Bamako	Risk reduction strategies	(Diallo & Bao, 2010; Musa & Abubakar, 2024)

The reviewed studies highlight several critical contributions of geospatial technologies to sustainable urban development. High-resolution satellite imagery and machine learning algorithms have improved the detection of informal settlement boundaries, enabling more accurate assessments of their encroachment into green spaces (Areola & Ikporukpo, 2020). Time-series analyses using vegetation indices such as NDVI and EVI have quantified degradation rates, revealing that informal settlements experience 2-3 times faster green space loss compared to planned urban areas (Hailu *et al.,* 2024). These findings have direct policy implications, supporting the delineation of urban growth boundaries and the prioritization of areas for green infrastructure investment.

Spatial modeling approaches have further enhanced the predictive capacity of urban studies. Cellular automata and agent-based models integrate remote sensing data with socio-economic variables to simulate future urban expansion scenarios under different policy interventions (Mzava *et al.,* 2019). Such models demonstrate that without targeted planning, African cities could lose 30-50% of their remaining green spaces within two decades. The integration of ecosystem service assessments, particularly through tools like InVEST, has enabled policymakers to quantify the economic value of green space preservation, strengthening the case for conservation in urban planning debates (Enoguanbor *et al.,* 2019). These applications collectively contribute to more evidence-based decision-making, though challenges remain in translating analytical insights into on-the-ground interventions.

The reviewed studies also reveal persistent methodological and data challenges that limit the full potential of GIS and remote sensing applications. Variations in image resolution, classification algorithms and validation approaches complicate cross-city comparisons, while cloud cover and data access constraints hinder consistent monitoring in tropical regions. Nevertheless, the emergence of open-data platforms and cloud computing solutions offers promising avenues to overcome these barriers, potentially democratizing access to geospatial tools for urban sustainability planning across African cities.

IV. Discussion

The synthesis of findings across the reviewed studies reveals several critical insights about the role of remote sensing in detecting green space degradation in African informal settlements. Taken together, the literature consistently demonstrates that informal settlement expansion follows distinct spatial-temporal patterns, often concentrated in ecologically sensitive areas; such as riparian zones and peri-urban forests (Graesser *et al.,* 2012). This encroachment leads to accelerated vegetation loss, with degradation rates in informal areas exceeding those in planned neighborhoods by 2-3 times (Hailu *et al.,* 2024). The evidence suggests that these changes are not merely incidental but reflect systemic urban governance failures, where weak land-use planning and tenure insecurity drive settlement expansion into green spaces.

A striking pattern emerges across studies regarding the socio-environmental trade-offs of green space degradation. While informal settlements provide essential housing for urban migrants, their unchecked growth diminishes ecosystem services critical for climate resilience and public health (Bante *et al.,* 2025). The loss of urban vegetation correlates strongly with elevated surface temperatures, reduced storm water absorption and increased respiratory illnesses in high-density settlements (Kanjir *et al.,* 2012). These findings challenge conventional urban development paradigms that prioritize short-term housing solutions over long-term environmental sustainability. The literature collectively underscores that green space preservation in informal settlements is not a luxury but a necessity for mitigating climate risks and improving living conditions.

Theoretical implications of this synthesis extend to conceptual frameworks linking urban informality with environmental change. Most studies adopt a land-use transition perspective, yet few integrate political ecology or urban political economy lenses to explain why degradation persists despite technical detection capabilities (Areola & Ikporukpo, 2020). This gap suggests a need for more interdisciplinary approaches that connect remote sensing observations with

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institutional analyses of land governance. The consistent finding that degradation hotspots align with areas of tenure ambiguity (Graesser *et al.,* 2012) points to underlying structural drivers—such as speculative land markets and exclusionary planning—that remote sensing alone cannot capture but must inform mitigation strategies.

Practically, the reviewed studies demonstrate that remote sensing tools can significantly enhance urban planning and policy interventions. The ability to map degradation hotspots in near-real-time enables targeted upgrading programs that balance housing needs with green infrastructure preservation (Mzava *et al.,* 2019). For example, object-based classification methods have proven effective in distinguishing between informal housing and vegetation in high-resolution imagery, providing actionable data for slum upgrading initiatives (Nambazo & Nazombe, 2024). However, the translation of these technical capabilities into policy action remains inconsistent, with many African cities lacking the institutional capacity to integrate geospatial data into decision-making processes.

Several methodological limitations constrain the generalizability of findings across different African urban contexts. The heavy reliance on Landsat and Sentinel imageries, while cost-effective, often fails to capture fine-scale degradation processes in densely built informal settlements (Hailu et al., 2024). Variations in classification algorithms and vegetation indices further complicate cross-study comparisons, with some studies using NDVI while others employ EVI or SAVI without clear justification. The underrepresentation of francophone African cities in the literature introduces geographic biases, potentially overlooking unique degradation patterns in West and Central Africa. Additionally, the scarcity of longitudinal studies spanning more than a decade limits understanding of long-term degradation trajectories and their cumulative impacts.

Future research should prioritize three key areas to address these gaps. First, there is a need for standardized protocols in remote sensing applications, including consistent vegetation indices, spatial resolutions and validation methods to enable robust cross-city comparisons. Second, studies must expand beyond technical detection to explore the institutional and socio-political barriers to green space preservation, perhaps through mixed-methods approaches combining remote sensing with qualitative governance analysis. Third, the field would benefit from more participatory mapping initiatives that engage informal settlement residents in data collection and interpretation, ensuring that remote sensing outputs align with local knowledge and priorities. Emerging technologies like drone-based sensors and AI-powered image analysis offer promising avenues to overcome current resolution limitations while reducing costs for resource-constrained municipalities.

The reviewed literature collectively highlights an urgent need to reframe green space degradation not just as an environmental issue but as a multidimensional urban equity challenge. The consistent evidence that residents of informal settlements bear the greatest burdens of vegetation loss, through heightened climate risks and reduced access to ecosystem services. This calls for planning approaches that simultaneously address housing deficits and environmental justice. Remote sensing technologies, while powerful, must be coupled with policy reforms that recognize informal settlers not as encroachers but as stakeholders in sustainable urban development. Only through such integrated approaches can African cities reconcile rapid urbanization with the preservation of vital green infrastructure.

V. Conclusion

This systematic review synthesizes the major insights on remote sensing approaches for detecting green space degradation in African informal settlements, addressing critical gaps in understanding the spatio-temporal dynamics of these interconnected processes. The findings demonstrate that informal settlement expansion follows distinct patterns of encroachment into ecologically sensitive areas, with degradation rates consistently exceeding those observed in planned urban areas. The loss of urban green spaces correlates strongly with elevated environmental risks, including urban heat islands and reduced climate resilience, disproportionately affecting vulnerable populations. While remote sensing provides valuable tools for monitoring these changes, methodological inconsistencies and data limitations constrain cross-city comparisons and long-term assessments.

The implications of this synthesis extend beyond technical detection capabilities to broader urban sustainability challenges. The evidence underscores that green space preservation in informal settlements is not merely an environmental concern but a fundamental component of equitable urban development. Future research should prioritize standardized protocols for remote sensing applications while integrating socio-political analyses of land governance. Emerging technologies, such as drone-based sensors and AI-powered image analysis offer promising avenues to overcome current resolution limitations. Ultimately, addressing green space degradation in African cities requires interdisciplinary approaches that combine technical monitoring with inclusive planning frameworks, ensuring that rapid urbanization does not come at the expense of ecological and social resilience.

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